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ABSTRACT

Work in the design and construction of virtual environments (VEs) is described from the standpoint of semiotic theory. It is advocated that well-constructed visual worlds can create in a person the feelings and cognitions that arise from being in the natural world and that interactions with computer-constructed VEs are mediated through signs. The Human Interface Technology Laboratory at the University of Washington uses VEs for specific instructional purposes and also uses the construction of VEs by students as a way for them to learn content. The design of VEs draws guidance from research in human factors and from the general principles of semiotics. Semiotic theory rests on the proposition that we cannot know the world as it truly is, but only through signs. In the conceptual framework for VEs, knowledge is constructed from information by students. A constructivist learning paradigm was used with 120 seventh and eighth graders who undertook the construction of VE worlds through a process based on semiotic-centered practices. The experiences of these students are described and followed with a discussion of how the sense of presence engendered by VEs can be increased through the manipulation of signs by learners. (Contains 55 references.) (SLD)

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Semiotics and the Design of Objects, Actions and Interactions in Virtual Environments.[1]

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"Were is the wisdom we have lost in knowledge?
Where is the knowledge we have lost in information?"

T.S. Eliot, Fourth chorus from "The Rock".

"La Nature est un temple où de vivants piliers
Laissent parfois sortir de confuses paroles;
L'homme y passent à travers des forêts de symboles
Qui l'observent avec des regards familiers."

Baudelaire, "Correspondences", from "Les Fleurs du Mal".

Introduction

In this paper we describe our work in the design and construction of virtual environments (VEs) from the standpoint of semiotic theory. This is a rather novel exercise for us, coming as we do from "mainstream" cognitive psychology. However, we have been struck by the value of using semiotics as a framework for the guidance and analysis of our work. After all, both Baudelaire, in the above citation, and Cunningham (1992) suggest that a person's communication with the natural world is unavoidably mediated through signs which sometimes introduces confusion into communication with and about the natural world. Our belief, explicated in what follows, that well-constructed virtual worlds can create in a person the same feelings and cognitions that arise from being in the natural world implies that interactions with VEs are likewise mediated through signs and are sometimes confusing.

We begin by explaining what we mean by a VE and describe how we are using VEs in education. We propose a theoretical framework that is a first attempt to reconcile our work to semiotic theory. We then look at how a group of grade seven children selected the signs to represent objects and events in four VEs they constructed. This is followed by a discussion of how the sense of "presence" engendered by VEs can be heightened through the judicious selection and use of icons and symbols. ("Presence" is the sensation the participant has of being in another place while visiting a VE.) Finally, we speculate about how the manipulation of signs by learners can lead to guidance on learning in the absence of real or virtual coaches.

A virtual environment is generated from sights, sounds and, in the not-too-distant future, physical sensations created by a computer from a database. It is an immersive environment that completely surrounds the participant in which sights and sounds, presented by stereo optical and auditory displays, are stable and locatable in three-dimensional space. To create an immersive VE, four conditions must be met. A participant's field of view must be wide enough so that objects in the world can be detected by peripheral and well as foveal vision. Ideally, this requires optical systems in head-mounted displays (HMDs) to subtend a visual angle of 200 degrees

horizontally and 120 degrees vertically (Furness, 1989). The position of the participant's head and at least one hand must be tracked with six degrees of freedom -- position on the X, Y and Z axes in the virtual space, and pitch, roll and yaw. The participant must be able to communicate with the VE through natural behaviors, such as looking, speaking and pointing, and not through an interface that uses a keyboard, mouse, joystick, touch screen, or other such device. This requires the use of transducers, such as gloves, wands, speech recognizers, gesture recognizers, that communicate participant behavior to the computer. In a well-designed VE, the participant is not aware of using an interface at all (M. Bricken, 1991). Finally, there should be negligible delays in the rate at which the virtual environment is updated in response to participants' movements and actions. Any noticeable lag between a participant's actions and ensuing changes in the VE's appearance causes confusion and, in a few cases, mild nausea referred to as "simulator sickness".

The work we describe in this paper uses technology that meets these four criteria, with the possible exception of the last one. Certain viewpoints in some of our VEs present the participant with more visual detail than others. When this is the case, the increased demands on the rendering software cause the rate at which the environment is redrawn to slow down. However,we have not found this to be a serious impediment to learning nor to our research.

These requirements for a VE are stringent. Others (Heim, 1993) give a much broader definition of VEs to include non-immersive environments. However, "desktop VR" (Lavroff, 1992) fails to provide first-person (Clancey, 1993) learning experiences and certainly does not engender presence. While non-immersive VEs are certainly effective for some kinds of learning (see Kozma et al., 1993) and are certainly more affordable than immersive systems, our work does not yet include them.

The Human Interface Technology Laboratory (HITL) at the University of Washington uses VEs in two ways for education. As might be expected, we build VEs for specific instructional purposes and see whether students learn about particular content when they visit them. For example, Byrne (Byrne, Furness & Winn, 1995) built a VE for grade eleven Chemistry students that allowed the construction of atoms and molecules by assembling them in the correct configurations. Byrne found that students learned the Chemistry content best if they interacted with the VE rather than just observing the construction process.

We also use the construction of VEs by students as a means for them to learn content. In fact, this is the technique we use most frequently since constructing VEs for school curriculum is very labor intensive which currently precludes the production of enough worlds to meet more than just one or two curriculum goals. We have found that students can learn world-building skills very rapidly (Bricken & Byrne, 1993) and have used the technique to teach AIDS awareness (Byrne, 1994) to develop cognitive and motor skills in children with neurological probblems (Osberg, 1994a) and to help students learn about the biological cycles operating in a wetlands ecosystem (Osberg, 1994b and later in this paper.) At the time of writing (April, 1995), we are actively building

VEs with over 400 children in 13 elementary, middle and high schools in the Puget Sound region of Washington.

Conceptual Framework: Semiotics and Virtual Envrionments

The conceptual framework that underlies our research on educational uses of VEs draws from a number of sources. From cognitive psychology comes our basic conception of how people learn and use what they have learned. Our experimental and instructional techniques are influenced by more recent ideas of knowledge construction and the situated and social nature of learning. The design of VEs draws guidance from research in human factors and from the general premises of semiotics.

Drawing these together, we propose that learning in VEs arises from interactions between participants and objects in VEs at four sequential levels. These are Data, Information, Knowledge and Wisdom. Each interaction transforms material from the current level to the next. Thus, interaction with data produces information; interaction with information produces knowledge; and interaction with knowledge produces wisdom. Semiotic theory enters into the picture mostly in the first two of these transformations. As we shall shortly see, the creation of information from data requires the creation or selection of signs, which can be accomplished by world designers, by participants themselves or by computer-driven transducers. The creation of knowledge from information involves the *use* of signs by learners whether as sources of knowledge or, internalized, as "tools for thought" (Salomon, 1979, 1988) that lead to knowledge construction. The development of wisdom from knowledge is usually not something that can be designed for and takes place over a long period, often an entire lifetime.

Generally, semiotic theory rests on the proposition that we cannot know the world as it truly is but only through signs (Cunningham, 1992; Driscoll, 1990; Driscoll & Lebow, 1992). One reason for this, that is important in the construction of VEs, is that people's inability to detect light beyond the visible spectrum, sound beyond the range of normal hearing, and so on, means that we can only ever be exposed to a relatively constricted "bandwidth" of data from the natural world. As Nagel (1974) has pointed out, we can never really know what it is like to be a bat even though we may be able to describe how echolocation works, transpose a bat's "sonar" down into the audible range and study its flight in slow motion. It follows, say semioticians, that knowledge has no objective existence independent of the knower and that our understanding of the world is therefore personal, inferential and context-dependent.

Learning begins when signs are created that stand for experience. The processes through which data are transformed into information are more physiological than cognitive and may therefore be characterised as "pre-attentive" (Arbib & Hanson, 1987; Marr, 1982). Moreover, we can exercise no willful control over them (Pylyshyn, 1984). This also implies that in our

conceptual framework data and information can only be *potentially* meaningful, not intrinsically so (see also Owen, 1985; Duong, 1994).

Information is data that have acquired structure. The natural world provides data about all its features and behaviors. Data are transmitted in many ways, as radiation in the electromagnetic spectrum, as sound through the propagation of waves through solids, liquids and gases and mechanically as texture, mass, temperature or viscosity. Because of the limitations imposed by our senses on our ability to receive these data, information can only be obtained about a small subset of these data and therefore is not a complete, true or objective mapping of the natural world. The first step in the acquisition of structure by data to become information is therefore a biologically imposed selection of those data that can be detected by the human senses (see also Maturana & Varela, 1987).

Our perceptual systems impose organization on detected data and this too occurs preattentively (Treisman, 1988; Marr, 1982). The structures that emerge as data are organized following by and large the principles of Gestalt psychology (Wertheimer, 1938) both for visual (Pomerantz, 1986; Pomerantz, Pristach and Carson, 1989) and auditory (Handel, 1989) perception. Information emerges from both the synthesis and analysis of data to allow us to discriminate one object from another and to configure objects into spatial and temporal relations (Winn, 1994). Thus, for example, following a series of actions in the visual pathway, described by Marr (1982), the visual scene is organized from edges and blobs into patterns and into discernible and potentially recognizable objects. The auditory stream is segmented (Bregman, 1990) by pitch and rhythm into patterns that are potentially recognizable as speech, musical motifs, or other sounds.

Both the selection of data and their organization are determined by the nature of human perception which operates preattentively. Therefore, even before we can begin to think about the information our senses present us with, that information is already an abstraction from data about the natural world. Our knowledge of the world is therefore based on representations of it not directly on the data it provides. We can only experience signs for temporally and spatially discriminated objects and the configurations that arise from their interrelationships. The same is also true of our perception of and knowledge about virtual environments. The same perceptual processes operate when we see and hear objects and events from inside an HMD as when we see and hear things in the natural world.

However, there are three important differences between creating information from data in natural and virtual environments. The first is that information is created in the natural world through selection by our senses from far more data than can possibly be detected and structured. In a VE, everything has to be added. One starts with the "void" (W. Bricken, 1991), adds objects and determines their behavior. This means that VEs are *designed* and that the signs found in them have to be selected or made by somebody.

The second difference between natural and virtual environments is that the signs that represent objects and events are entirely computer-generated. This means they can appear in any form and may behave in any manner whatsoever. For example, a fixed object may move away from you as you walk towards it rather than appearing to get closer. An object may stay suspended in mid air when you "drop" it.

The third difference is that a VE can easily present information from data that people cannot usually detect. Because a VE is created from a digital database, it can present information about any data that can be expressed in a digital format. Today, this means just about anything. Data that normally escape the human senses can be captured by sensors and converted by transducers into signs that humans can perceive and examine. A marine depth-sounder bounces sounds I cannot hear off the sea-bottom I cannot see and creates either a graph (iconic sign) or numerical readout in fathoms (symbolic sign) that represents the depth and contour of the bottom. The transduction process (Winn, 1993) vastly expands the data from which VEs can create informational signs.

These three points remind us that, however strong a sense of "presence" it may engender, a VE is not the real thing. The creation of signs from data in a VE is therefore a two-step process. First, information designers (who could well be, and in our work usually are, the students/participants themselves) create signs that hold the information they wish to place in the VE. Second, when the participant enters the VE, these signs function as data from which the participant will select and find information. For example, in Byrne's "Chemistry World" (Byrne, Furness & Winn, 1995), students build atoms and molecules by putting virtual protons, neutrons and electrons together by hand. The Chemistry curriculum largely determined what information should be presented. The signs through which information, such as subatomic particles, were to be shown required design decisions that drew on graphic conventions (protons are positive and therefore are best shown by a 3-D "plus" sign), pedagogy (how should signs behave when a student makes a mistake?) and human factors (how big should each object appear to be so that it seems natural to pick it up and carry it about?) In the four student-built worlds that represented wetlands ecology, described more fully below, the students themselves faced similar design decisions. Interestingly, it was easy for them to decide how to represent objects that could be shown as iconic signs, such as animals and plants. However, information that required transduction of data and representation as symbols, such as free nitrogen or energy, required a great deal of discussion that never led to entirely satisfactory resolution. In both worlds, there is no guarantee, of course, that participants will attend to the information in the signs they encounter in the VE any more than you can guarantee they will notice certain things as they look around in the natural world.

In our conceptual framework, knowledge is *constructed* from information by students. We therefore subscribe to many of the tenets of "constructivism" put forth by those who advocate such approaches for educational technology (Duffy & Jonassen, 1992; Duffy, Lowyck & Jonassen, 1993). This means that,

as far as possible, we want students to select their own signs in virtual environments and to come to know the world in terms that are meaningful to them, not in terms that are given by a teacher or world designer. This approach often gives rise to surprises. For instance, while discussing what objects to place in a VE they were building that embodied the principles and actions of the carbon dioxide cycle, a group of grade seven students had to deal with one group member who wanted to have a basketball in the VE. The objects the other students proposed were the expected animals and plants and the group as a whole was hostile to the suggestion. However, the student's reasoning was impeccable: Basketball players are energetic, breathe in a lot of oxygen and exhale a lot of carbon dioxide; when they blow up basketballs, they fill them with carbon dioxide. For this student, the basketball represented the way respiration changes oxygen into carbon dioxide and also represented the sports context in which the process was meaningful for him. (The group process being democratic, this student's suggestion was voted down by the others and no basketball appeared in the VE!)

When students build VEs, "construction" takes on additional significance. Perhaps we are close to what Harel and Papert (1991) call "construct*ion*ism" rather than "construct*iv*ism". At the same time as they are constructing knowledge, the students are also constructing "physical" environments in which that knowledge is put to use. They can construct anything from a wetlands ecosystem to an atom or molecule, from a tree to a brain. They can make any event occur in their VE that they want, whether it mimics scientifically accepted principles of the natural world or something entirely from their own imaginations. They can create iconic signs that represent familiar objects and are likely to be recognized easily by others; or they can invent symbolic signs that form part of a framing metaphor they have chosen for their VE. Finally, they are constructing environments in which they control behaviors of chosen objects by interacting with them physically -- picking them up, carrying them to a new place, placing them in interaction with other objects. Knowledge construction follows from the phsycial construction of an environment that functions as the student wants it to in a direct, visceral manner.

Finally, knowledge becomes wisdom when it is used effectively. We agree with Sternberg (1990, p.4) that "wisdom is a virtue providing a compelling guide to action." Unless knowledge is used, it is "inert" (Cognition and Technology Group at Vanderbilt, 1990), disconnected both from a meaningful context when it was learned and from a context in which it can be wisely applied. We believe that VEs have the same potential for "anchoring" instruction in contexts that are meaningful to students like the "Jasper" video adventures, designed to teach math by the Cognition and Technology Group at Vanderbilt (1992), or many of the exercises using "Bubble Dialogue", developed by McMann & O'Neil (1993) to develop communication and social skills. However, it would be audacious to claim that the VEs our students have developed have enabled them to use their knowledge with wisdom. The common perception of wisdom, and recent studies of its development (Csikszentmihalyi & Rathunde, 1990; Labouvie-Vief, 1990), demonstrate that it develops slowly over time. Our research has not been able to study either students working

with VEs over extended periods of time nor the consequences of that activity over a lifetime.

World Design: The Kellogg Middle School Project.

A VE is a metaphorical representation of either physical reality, an abstract representation of some aspect of reality, or a combination of both. Since semiotics is based on the individuals' use of signs (metaphorical representations of some aspect of the individuals knowledge), a VE, as a teaching and learning tool, fits well within the semiotic framework. This is especially true in the case where virtual learning environments are created by the students themselves. At Kellogg Middle School in Seattle, Washington, we had the opportunity to undertake such a world-building activity, and based our process on semiotic-centered practices.

The 120 students in the mixed 7th and 8th grade classes were used to the constructivist learning paradigm, since all 5 teachers involved in the project studied and employed constructivist techniques on a regular basis. The focus of the classroom was on personal inquiry within a larger subject domain. Our Wetlands project fit within this same model.

As part of their fall curriculum, these two classrooms were to study wetlands ecology. The teachers and HIT Lab staff chose this portion of the curriculum as likely to be suitable for a world-building activity. When we arrived, the students were very excited about the prospect of developing a virtual learning environment as part of their wetlands sequence. We asked a great deal of the students; to learn about wetlands ecology, to study a particular aspect of the wetlands ecosystem in detail and to develop a virtual environment that represented their understanding of that aspect, to learn how to model in three dimensions on the computer, and to become, in essence, instructional designers.

Creating a virtual environment is a four-step process: Planning, Building, Programming, and Experiencing. It is during the Planning and Building stages that we were able to see just how students were selecting the icons, indexes, and symbols (Houser, 1987) for their virtual environment.

By the time we started the planning stage, students had a fair understanding about what the basic contents of a wetland might be. In discussing the objects that the students wanted to include, there were many that were suggested that would have been considered relatively obvious: cattails, frogs, turtles, water, an alligator, the sun, clouds, etc. Planning became particularly interesting when the students abandoned their pre-conceived notions of what should be in a wetland, and looked beneath the surface, both figuratively and in actuality. In addition to the student who wanted to include a basketball, one student wanted to look for fossilized remains in the peat bog that formed the wetland. Another wanted to include a car that had gone off the road and was rusting in the pond, and would build an

entire story about how the car had swerved off the road and landed there. And another student wanted to build a condominium development, since that is what we do to wetlands. It was clear from these examples that some of the students were able to bring a great deal of their personal experience into their representation of a wetland. This illustrates both Bruner's (1990) point of view that individuals' personal stories are important in meaning-making, and, more generally, Cunningham's (1992) claim that knowledge and knower cannot be separated.

Words, pictures, bodily movement and the like can become part of our "Umwelt" (von Uexkull, 1982) – our personal, internalized view of the world -- even though they may mark objects that have no literal basis in the physical world (i.e. culture). The fact that humans can utilize signs that are arbitrary and need have no existence in their immediate experience is what makes thought possible and distinctly human. Knowledge, therefore does not consist of objects or entities that we acquire. Knowledge is better thought of as knowing, or as a process. Through our experience in the world, we build ways of knowing, structures that determine our current understanding. And via these structures, we literally construct our knowledge dynamically as we interact with the world.

We observed specific instances of this kind of knowledge construction as we observed the students talking about how to represent abstract concepts, such as nitrogen, fixed nitrogen and energy from the sun. Signs that represent abstract concepts can be truly and completely arbitrary. And yet, students chose to embed meaning in the signs that they selected, through their form, color, or how they were transformed. For example, the students decided to represent free nitrogen as a yellow sphere. This in and of itself is not remarkable. However, when free nitrogen changes to fixed nitrogen through one of several processes, that same yellow sphere was augmented by four smaller spheres, representing the additional chemical components that are now a part of the nitrogen, while retaining the original symbol of the free nitrogen itself. Thus, the students' understanding of the nitrogen-fixing process as the addition of chemical components was represented by a symbol that acquired its own components as a result of student action in the VE.

Another example of this embedded meaning-making took place during discussion about the color and form of signs for energy from the sun and water vapor, two components of the water cycle. The process by which water in its various forms moves through the wetland (and all other environments, for that matter) is by evaporation, condensation, and precipitation. In representing these three interrelated processes, students wanted a clear way of conveying what needed to mix with what in the environment. In discussing color, there was no disagreement that energy from the sun should be yellow, as the sun is yellow in these students' perception, and that water vapor should be blue, since the preponderance of water that we see on the earth appears blue in color. Students could clearly map the color onto the representation as a clue to the participant about what these arbitrary signs might represent.

The next topic of discussion was form-- what does energy from the sun look like? Is it a ray? A string of little suns streaming from the big sun to the earth? Is it a big yellow blanket? How can we represent an object that can be used to create the water vapor necessary to illustrate the water cycle? Should the energy move towards the earth, or should the participant move it? All of these questions were important to the students. In the end, the symbol they selected for energy from the sun was a yellow bolt of energy, since they could also agree that what the sun provides is energy in the form of heat. This bolt was easy to pick up and take down to the lake, where the bolt mixed with the lake to generate water vapor.

The discussion of the form water vapor should take was also revealing. Should it be a series of droplets? Just a dense fog? Should the water vapor automatically move up towards the sky once it appears? In the end, the students elected to create a series of three semi-transparent (since water vapor is essentially transparent) arrows that would appear just above the lake, and point up towards the sky. As with the bolt of energy, they also felt that it was more important that the participant be able to grab the water vapor, and manually move it towards the cloud, representing the process of condensation.

The process by which the students, with the assistance of both their regular teachers and HIT Lab staff, came to these conclusions illustrated some important pedagogical implications of sign-creation. In traditional classrooms, the underlying pedagogy is based on the metaphor "student as container" and "teacher as knowledge bearer". This approach would certainly have precluded the creativity and richness inherent in the discussions about the students' view of what constitutes a wetland, and how to convey abstract information within that environment. As Cunningham (1992) points out: "We teach teachers those techniques that have been scientifically shown to efficiently and effectively communicate this knowledge to students: classroom organization and management, questioning techniques, lecturing, discussion, preparation of materials, and so forth. All are geared toward effective communication." (p. 168)

In contrast, the semiotic view, to which we subscribed in the wetlands project, of "student as meaning maker" and "teacher as facilitator" will result in an entirely different set of teaching and learning practices. In this paradigm, the student and the teacher work together through dialogue to inform one another about their perceptions and to create personal meaning. This approach has unlimited potential for meaning-making or knowledge construction. In the view of Cunningham (1992), Landow (1989), Gardner (1983), and Friere (1970), our job as educators is to provide a rich environment in which to build these structures. As specifically stated by Cunningham: "We have to shift to pedagogical strategies that promote a student's ability to see that multiple perspectives may be brought to bear on a problem; that coming to understand another's view requires dialogue, not simply listening; that learning can and often should occur in a social setting, not as some private act; and that learning should be situated within realistic contexts about which the students care or about which they have made some kind of

commitment." (p. 181). Based on what we discovered at Kellogg Middle School and in other projects where we have allowed the students free rein to create their VEs based on their own knowledge and imagination, we have learned the value of the semiotic approach to learning and pedagogy. Building VEs provides a great opportunity to shift the learning and teaching metaphor towards one with a greater emphasis on semiotics.

World Design: The Nature and Importance of Presence.

Real-time visual and auditory cues afforded by the technology, described previously, with which we create VEs, combined with a participant's ability to interact with objects in the virtual environment, often lead participants to have a strong sense that they are "in a place". They feel they are inside the computer simulated environment, rather than just looking at a video display. This psychological sensation, known as "presence", is thought to be the essence of virtual reality. VR researchers speculate that presence improves cognitive and motor performance within a virtual environment, and improves learning and transfer of training. VR reduces or removes the interface between the user and the computer (M. Bricken, 1991; Winn, 1993), reducing the amount of attention participants must direct at developing an understanding of the computer interface itself.

Despite this improvement over traditional computer interfaces, students in a virtual environment are still performing a divided attention task. Part of their attention is drawn into the virtual environment, but at some level the student remains aware of the fact that they are still standing in the laboratory or classroom wearing a bulky helmet. Feelings of presence are therefore likely correlated with the amount of attention drawn into the virtual world and away from the laboratory. Manipulations of VR designs that create a stronger sense of presence (see Hoffman, Prothero, and Wells, in preparation) likely draw more attention into the VE.

Increasing the amount of attention paid to information can improve recall. For instance, emotionally arousing events typically draw more attention and are better remembered than emotionally neutral events (e.g., Christianson, Loftus, Hoffman and Loftus, 1989). (Interestingly, Laurel [1993] suggests that researchers think of presence as an emotion.) In order to maximize the quality of the human/computer interface and to increase the likelihood that students will pay attention and learn the information presented in VEs, designers should attempt to maximize the sensation of presence in VEs.

This task is made easier by the fact that VR allows multimodal representation of objects. When considering how to represent an object in a way that maximizes the feeling of first-person participation and the feeling of presence, world builders should consider what sensory inputs will be available. For instance, hearing a coke can fall from the machine when buying a virtual pop increases subject's psychological experience that "it's the real thing",

when the sound is appropriate and accurately located (Barfield and Hendrix, 1995). In contrast, hearing a balloon bark when punctured could conceivably decrease the student's sense of presence.

The provision of tactile cues in VEs is technically difficult and ergonomically cumbersome. As a result, VR systems that give tactile feedback are not common. In the real world, tactile cues are largely processed without our awareness, but make a critical contribution to our sense of self and our construction of reality. A number of researchers are developing tactile-feedback devices. For example, researchers at MITI's Research Institute in Tsukuba, Japan, have constructed a robot-like force-feedback device. Participants push a handle along a virtual wall. The robot stops the participant's hand in appropriate places as if a real wall were blocking motion. Eventually, such haptic feedback will likely become an important addition to commercially available virtual reality engines.

In the meantime, Hoffman, Winn, Hollander, and Rousseau (in progress) are developing a cheap shortcut. In a proposed study, students in a "see only" condition will see a 3-D virtual image. Other students in a "see and feel" condition will see the same image, but will also be able to reach out and touch the virtual objects. For the "see and feel" condition, we simply place real objects (for example, a rubber ball) on a table within the participants' grasp in spatial locations matching the approximate location of the virtual object (a blue ball in the VE). This technique, which we call "tactile augmentation", is a mixture of real and virtual representations. Experiments designed to assess whether tactile augmentation increases the sense of presence and whether it enhances learning in the virtual world are presently underway.

According to Laurel (1993, p 117), virtual reality is more than a new tool, it is a new communication medium: "In task-oriented applications, new technologies are allowing researchers to replace indirect or symbolic representations and manipulations with direct, concrete ones -- for example, physically pointing or speaking, as opposed to typing, spatial and graphical representations of data as opposed to textual representations. Likewise, the evolution of natural-language interfaces is beginning to replace the elaborate conventions of menu-based and command-based systems with systems that employ language in ways that are mimetic of real-world activities like conversation and question and answer". She emphasizes that VR gives participants (students) experiences, as opposed to information. In our terms, VE's create knowledge from information through experience. She states "the human is an indispensible ingredient of the representation, since it is only through the person's actions that all dimensions of the representation can be manifest". In light of this, one of the roles of the world designer is to create representations of objects and environments that provide contexts for action.

Presence is enhanced when VR allows for changes in the behavioral state or representation of a sign in response to the participant's actions (i.e., the creation of new signs from existing signs). This "action" feature is very valuable. When a student in Byrne's Chemistry world fills the outer orbital shell by placing two electrons near the nucleus, a huge bulb representing a

completed orbital shell appears in the world. The element of surprise at the metamorphosis of old signs into new can be of great educational value. Sign metamorphosis like this should cue subjects about what they should do next. For example, in the water-cycle world, touching a cloud makes rain, suggesting that doing something with the rain is the next step. And, as we saw above, correctly fixing free nitrogen changes the symbol that the student manipulates, suggesting that fixed nitrogen needs to be used for the next task.

Finally, a high level of presence, which draws students' attention into the VE, can make it easier for them to actively figure out how the world works. Constructivist world designs, such as we described earlier, can encourage scientific thinking. The students make an educated guess about what they should do next, and they "test their hunch". Encouraging students to stand in a scientist's shoes is a successful approach to science education (see Bruer, 1993). Rather than passively memorizing the fruits of the labor of countless faceless scientists, students formulate and test their own hypotheses about how the world works. If a high level of presence allows the results of their operations upon objects in a VE to be immediate and to be meaningful in the context the VE provides, thus confirming or disconfirming their hypothesis, their understanding can be improved. On the other hand, low presence allows the intrusion of the real world into the VE, distracting them and preventing them from building their own understanding.

World Design: Embedding Guidance in VEs.

How the *behaviors* of objects are represented in a VE is important to providing guidance to students who are having difficulty constructing knowledge. One of the biggest challenges facing designers of VEs for both education and training is how to provide assistance to participants without just telling them what to do. The simplest approach, which we use when necessary, is for an observer to give verbal hints and suggestions to a student who is immersed in a VE. However, as one might expect, this reduces presence as attention is drawn away from the VE and into the world outside. Placing an "avatar" into the VE with the student is another approach. The avatar observes the student's actions and provides guidance when necessary. While this approach maintains and perhaps even enhances presence, it is difficult to implement. A third approach is to build guidance into the very behavior of the VE. This section provides a brief discussion of this technique.

As we explained in the previous section, presence, and thus learning, are improved if signs change their appearance in meaningful ways as a result of participant actions. However, if a student performs an unanticipated action (a creative one, a wrong one), the sign typically does nothing. We feel that this is the equivalent of a standard CAI program printing "Answer unrecognized" onto the screen. It certainly causes frustration and confusion. There are other possibilities, some of which were described by Winn & Bricken (1992) in a VE that obeyed the laws of Algebra rather than the laws of the Newtonian universe. The following example is taken from their article.

If, during the solution of an algebra problem, a term is moved from one side of the equals sign to the other, the term's sign changes from positive to negative or vice versa. Assume that this action is symbolized by inverting the symbol used to represent the term, in this case a colored block. One of three things could happen when a student moves a block across an equals sign without inverting it. First, the VE might allow the student to make this error. In this case, the solution to the problem is "bugged" and, once the student realizes subsequently an error has been made, the steps in the solution must be traced back to where the bug occurred. In short, no guidance at all requires a student in a VE to engage in trouble-shooting. Second, the VE might make the block float back to its original position. This is what happens to misplaced atomic particles in Byrne's Chemistry World (Byrne et al. 1995). In this case, the student knows an error has been made, but is not told what it is. The student repeats the step using a different action. In the third possibility, the block inverts itself and settles into place. The student knows an error was made and also what the correct action should have been. The VE is self-correcting.

There is nothing startling about this example. The various behaviors of the algebraic term correspond to fairly standard practices of providing feedback to students. However, the ways of representing the behavior of objects in VEs is, within the limits of the technology, unlimited. Because objects in VEs are themselves signs, they can be programmed to behave in any way at all. This means that in VEs such as the Algebra world, whose purpose is more didactic than constructivist, pedagogy can be built seamlessly into the environment itself. Thus, presence can be maintained while students get guidance on specific actions they must perform. In VEs designed to permit students more freedom to construct knowledge for themselves, imagination could be stimulated by introducing a measure of randomness into behaviors. In cases where VEs are built by students themselves, and where the activity of building a VE rather than visiting one is how learning is encouraged, students' experimenting with how to represent procedures and principles as behaviors is an act of symbol-creation and meaning-making that serves a similar purpose as deciding how to represent each object. And like deciding how to represent objects, chosing and experimenting with behaviors that act as symbols for abstract procedures and principles, like fixing nitrogen or changing electron spin, helps students construct knowledge from information.

Conclusion.

It is premature to draw hard and fast conclusions about the effectiveness of either building or visiting VEs for knowledge construction by students. The technology is still too young and the research too fragmented. However, we do have evidence that visiting a VE improved students' understanding of basic concepts in chemistry (Byrne et al. 1995) and can report here that the world-building project at Kellogg Middle School produced significant increases in students' understanding of wetlands ecology. We also know, from the projects described here and from others, that students have

little difficulty with the software used for building worlds (Bricken & Byrne, 1993), that they enjoy doing so and can do so in a collaborative manner (Osberg, 1994a).

It is also somewhat premature to conclude that semiotic theory is the best tool by means of which to conceptualize, study and discuss learning in VEs. In this paper, we have made a first attempt to explain where we think the most fruitful links between semiotics and VEs are likely to be found. Still, the fact that people who design, build and visit VEs are dealing with signs that represent reality in some impoverished way is far more self-evident than it is, perhaps, for those working in similar ways with "real" environments. This means that, within our conceptual framework, it is both necessary and useful to think of transforming data into information as the creation of signs, whether this action is performed by VE designers, students themselves, or computer-driven transducers.

The construction of knowledge from information has many of the characteristics of "semiosis" (Cunningham, 1992) or meaning-making. We believe that, in the case of learning in VEs, presence must be established at a high level for knowledge construction to be successful. The more a student is drawn into a VE by the ability to interact with it naturally, by the conviction of being in another place and by the way objects and their behaviors are represented, the more likely it seems that the student will construct personal and meaningful knowledge of the world. However, our research agenda that will confirm or refute this assumption is still in its early stages.

And what of wisdom? We certainly hope that what our students acquire by working with us is "a virtue" and that it provides "a guide for action" (Sternberg, 1990). It may be that the actions of physically building and interacting with representations of objects may accelerate students' ability to act on the knowledge they have constructed. However, we are still persuaded that the acquisition of wisdom takes a long time. This suggests the need for longitudinal studies of students who have enjoyed extended experiences in VEs. The scope of any such studies would be immense, implying, perhaps, that the question of wisdom can only be answered when we know whether VEs improve or impoverish our quality of life in general. In short, only time will tell.

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